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GLACIOMARINE SEDIMENTATION AND PALEOGLACIAL SETTING OF MARIAN COVE, KING GEORGE ISLAND, ANTARCTICA

H. I. YOON, Y. KIM, M. Y. CHOE and S. H. NAM

Korea Ocean Research and Development Institute,
Ansan P.O. Box 29, Seoul 425–600, Republic of Korea

Abstract: The sea floor of Marian Cove is highly rugged and is covered by a very thin drape of sediments, suggesting that this area has been recently eroded by glaciers with minimal posterosional sediment accumulation. A piston core shows a vertical lithofacies, changing from waterlain till through meltwater deposits to pebbly mud as the result of a combination of ice rafting and suspended sedimentation. A reconstruction of the glacial history of this area since the late glacial maximum shows grounded ice filling the cove in late Holocene time and retreat of the ice sheet from the cove at least 1300 yrs BP, accompanyed by a marine transgression.

Key words: waterlain till, meltwater plume, ice rafting, Marian Cove

1. Introduction

Climate, as a ruling factor in respect to weathering, controls the rate and mechanism by which terrigenous sediment is supplied to the glacial marine environment, although the oceanographic and physiographic constraints may be important to the resulting sedimentary facies (DOMACK *et al.*, 1988). It is particularly effective in sub-polar and/or temperate glacial settings where meltwater plumes and iceberg drifting appear to play an important role in sediment transportation (HOSKIN and BURREL, 1972; ANDERSON *et al.*, 1980).

Marian Cove is a shallow (less than 100 m), ice-influenced fjord located southwest of King George Island, Antarctica (Fig. 1). It is bounded by the Weaver Peninsula to the northwest and the Barton Peninsula to the southeast, and is bathymetrically separated from Maxwell Bay by a shallow (less than 40 m) submarine sill. A small valley glacier, draining southwest from the cove head, debouches large amounts of icebergs and turbid meltwater into the cove during the melt season. Small meltwater streams are common near landmasses and form small outwash fans on the coast. Geology of the surrounding landmasses is composed of Upper Jurassic or Lower Tertiary basaltic andesite intruded by dolerite and quartz diorite (REX, 1976; DAVIS, 1982; SMELLIE *et al.*, 1984; JIN and JWA, 1990).

The climate of Marian Cove is relatively warm and humid with high precipitation (REYNOLD, 1981), which leads to a sub-polar glacial setting where a large amount of terrigenous sediment enters the marine environment in the form of turbid meltwater plumes (POWELL, 1983): the weather data observed for two years at the King Sejong

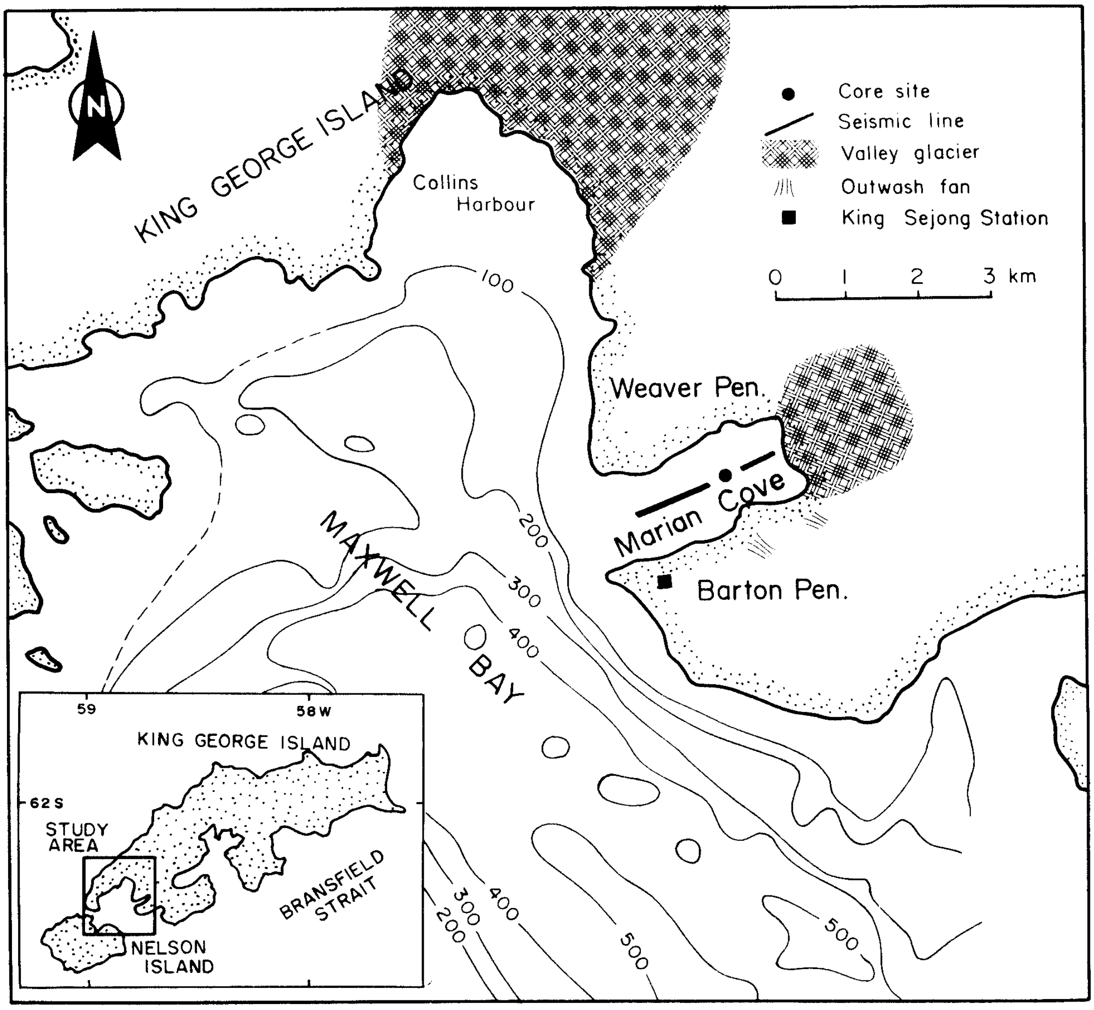

Fig. 1. A map showing the location of the seismic line and piston core. Also shown is the glacial setting of the study area (from GRIFFITH *and* ANDERSON*, 1989). Contours in meters.*

Station (LEE, 1989) show that the average relative humidity is 86% and the maximum average annual air temperature is above 10.4°C. Weathered terrigenous clastics are thus delivered through turbid water plumes or drifting icebergs into Marian Cove (PARK *et al.*, 1988; GRIFFITH and ANDERSON, 1989).

During February 1993, seismic profiling and piston coring were conducted in Marian Cove to infer the sedimentary processes forming glaciomarine sediments and to examine the recent glacial history of the area.

2. Methods

About 4 km-long seismic reflection (3.5 kHz) records and a 3 m-long piston core (7 cm in diameter) were obtained from Marian Cove. The core was split into half for X-radiography and subsampling. Subsamples were analyzed for grain size, water content, organic matter and calcium carbonate contents. Grain size distribution for the $-1.0\ \phi$ to $4.0\ \phi$ size fractions were determined by dry sieving. Finer fractions (to 10.0

ϕ) were analyzed by a Micrometrics Sedigraph 5000D. Cumulative curves, mean grain size and sorting values (FOLK and WARD, 1957) were produced from the combined data by a computer program. The size of pebbles were obtained by averaging long axes of all clasts greater than 2 mm. Calcium carbonate content was gasometrically measured with a Bernard calcimeter, and organic matter by combustion on loss at 550°C. Physical sedimentary and biogenic structures were revealed through X-radiography of 1 cm thick sediment slabs.

3. Seismic Profile and Core Sediments

A high resolution (3.5 kHz) seismic record from Marian Cove reveals that the seafloor is highly rugged and covered with an extremely thin (less than 6 m) sediment drape showing acoustically chaotic reflectors (Fig. 2). No evidence of sediments ponding is found, even on small bathymetric depressions. Core sediment recovered from this sediment drape can be divided into three lithofacies within a fining upward sequence: 1) boulder bed at the base (unit I); 2) interlaminated sand and mud (unit II) from 1 to 1.4 m, from the top and; 3) pebbly mud in the upper 1 m (unit III) (Fig. 3).

Unit I represents the 30 cm-thick basal part of the core. It consists of massive, very hard (60 kPa), light grey, clast-supported gravels with minor amount of finer matrix (Fig. 3c). The gravel fraction consists of pebble to boulder grade clasts, ranging from 1 to 7 cm in size. They are highly striated and faceted indicating reworking by a glacier. The finer matrix is composed of poorly sorted (range from 3.5 to 4.0 ϕ) sandy muds with a mean grain size of 3.0 to 5.0 ϕ (Fig. 4). Organic matter and water content are extremely low (approximately 2 and 20%, respectively), but $CaCO_3$ content is relatively high (more than 1%) (Fig. 4). The diatom assemblage is very low in number and diversity with occasional occurrence of diatom debris (i.e. *Nitzschia curta* and *Nitzschia kerguelensis*).

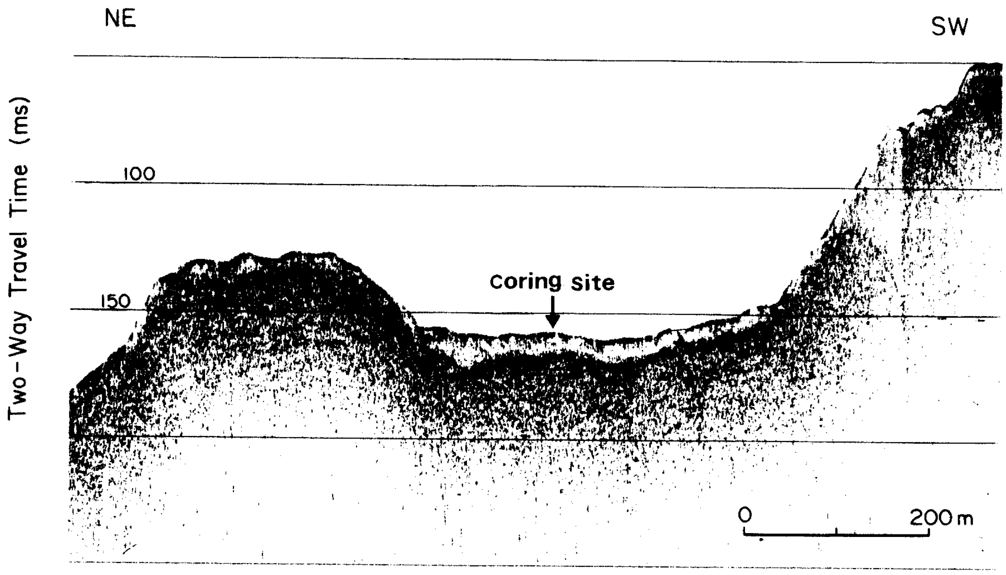

Fig. 2. 3.5 kHz profile showing rugged basement of Marian Cove covered with acoustically chaotic ice-proximal deposits.

Fig. 3. *X-radiograph of the sediment core from Marian Cove: (a) unit III=pebbly mud (core depth;, 44–65 cm), A=shell* (Yoldia eightsi), D=*ice-rafted dropstone; (b)unit II=interlaminated sand and mud (core depth, 100–121 cm); and (c) unit I=waterlain till (core depth, 151–172 cm).*

Unit II consist of interlaminated sand and mud (Fig. 3b). This unit occurs with the repetition of alternating sequences of very fine sand to sandy mud. They uniformly drape underlying surfaces, and current bedding is not observed. This unit is poorly sorted (range from 2.5 to 4.0 ϕ) and shows a heterogeneous texture with a mean grain size of 3.5 to 6.5 ϕ (Fig. 4). Unit II has both organic matter and $CaCO_3$ contents (less than 2 and 25%, respectively) similar to those of unit I, but water content is slightly higher (Fig. 4). Microfossils are rare, showing a very low diatom assemblage in number.

Unit III is about 100 cm thick and represents the uppermost part of the core (Fig. 3a). It consists of pale grey (5Y 7/3) silty mud with occasionally scattered gravels. This sediment is massive and partly mottled with a mean grain size of 6.7 to 7.3 ϕ (Fig. 4). Grain size frequency curves show a strong bimodality with the main mode at close to 8 ϕ and the second mode at approximately -3 ϕ (Fig. 5). Intact shell (i.e. *Yoldia eightsi*) and biogenic structures are occasionally observed (Fig. 3a). Organic matter and water contents are higher (more than 3 and 60%, respectively) than those in units I and II due to the appreciable amount of mud, but $CaCO_3$ content is negligible (Fig. 4). The

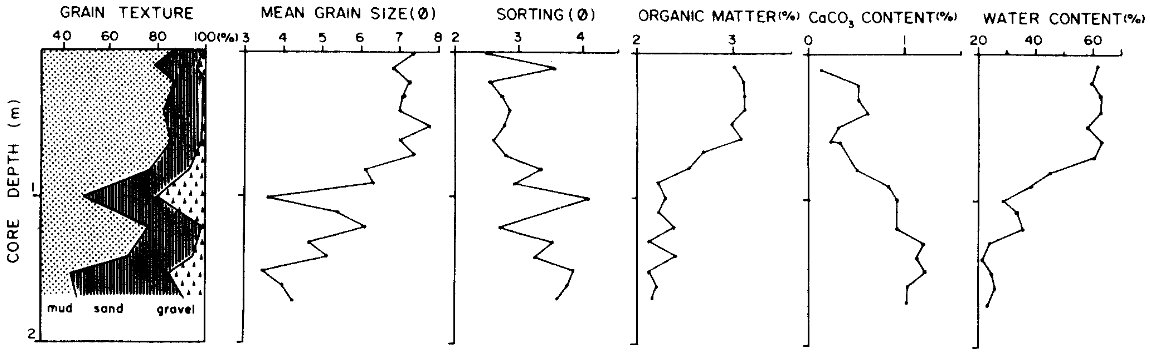

Fig. 4. *Vertical variations of sedimentological and geochemical parameters of the sediment core from Marian Cove.*

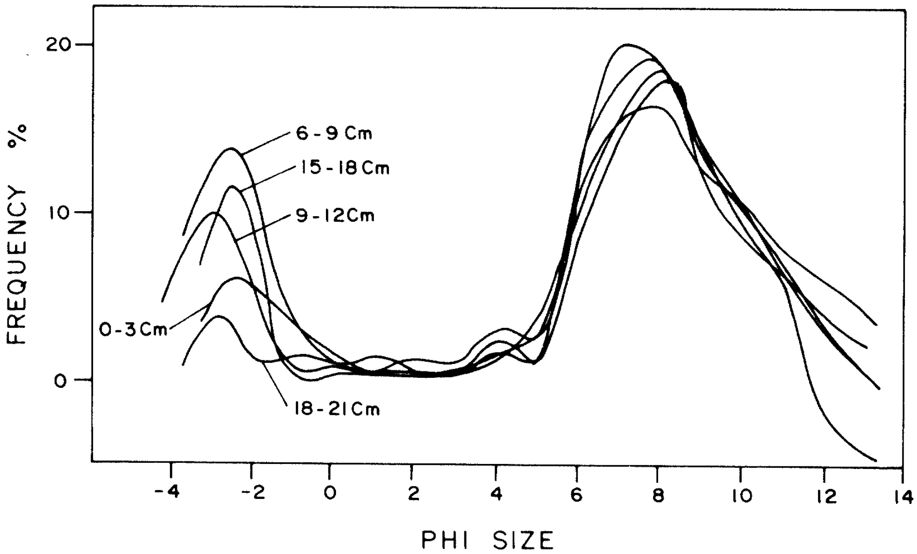

Fig. 5. *Frequency curves of grain size for pebbly mud (unit III) showing distinct bimodality in size distribution.*

microfossil assemblage is very high including diatoms, radiolaria, foraminifera and spongy spicules.

4. Depositional Processes

The bottom of Marian Cove is characterized by a very thin layer of sediments indicating very recent glacial retreat and the limited input of post-glacial terrigenous sediment. The core sediments become fine upward indicating a gradual environmental change of reducing ice impact.

Clast-supported fabric, very low organic content, over compaction, and lack of microfossils of the boulder bed (unit I) indicate that it is a waterlain till deposited by continuous rain-out of basal glacial debris just seaward of the grounding line during the period of ice retreat (Fig. 3c). The waterlain till is similar to those in the Ross Sea in that the finer matrix includes reworked diatoms. Kim *et al.* (1991) have examined diatoms in waterlain till of Marian Cove and concluded that the diatoms have been reworked by grounded ice. This finer matrix is therefore thought to be a result of reworking and incorporation of preglacial sediments into the waterlain till of Marian Cove.

Macro- and microfaunal evidence in the unit of interlaminated sand and mud is extremely sparse in comparison with other depositional units, suggesting that sedimentation may have been quite rapid during the deposition of this unit (Fig. 3b). Rhythmic pattern, absence of current structure and frequency of dropstones indicate that the unit of interlaminated sand and mud represents a suspension deposit derived from turbid midflow and/or overflow plumes in the inner and outer proximal zones (Domack, 1984). A preliminary hydrographic survey in the neighboring Admiralty Bay reveals that summer-time turbid plumes are restricted to the surface layer, suggesting that meltwater processes and terrigenous sediment transport are in the form of overflow plumes (Domack, 1988). These observations all suggest that the interlaminated sand and mud would be deposited mainly by suspension settling from turbid meltwater plumes during the austral summer.

Pebbly mud, as suggested by fine-grain size with abundant ice-rafted debris, bimodal size distribution and absence of current structure, is interpreted as a suspension deposit associated with drifting icebergs in a quiescent bottom condition. Preservation of intact shell and extensive bioturbation are indirect evidence of a low rate of terrigenous sedimentation relative to the underlying sequences (Fig. 3a). Anderson *et al.* (1980) identified these deposits as compound glacial marine sediments derived mainly from a combination of fine-grained particles from suspension and coarser particles from ice-rafting. Faint laminations within this unit may represent a pulse of turbid meltwater during the melting season.

5. Depositional History

The occurrence of waterlain till (unit I) in the core is clear evidence for ice grounding in Marian Cove (Fig. 6). According to the preliminary result of ^{210}Pb dating of surface sediments (Kim, 1989), the accumulation rate of sediments in Marian Cove is 0.75 mm/yr. Although this value cannot be extrapolated downcore into the meltwater deposits and waterlain till, which probably had much higher rates of sedimentation, it can be postulated that the waterlain till below the top 100 cm accumulated before 1300 yrs BP. That means, Marian Cove was completely ice-covered until about 1300 yrs BP. Indeed, it appears that the ice sheet very recently retreated from Marian Cove, judging by the thinness of the caping pebbly mud (unit III). Palaeoclimatic study for lake sediments on Livingstone Island (Bjorck *et al.*, 1991) additionally supports this recent glacial advance, demonstrating that a slightly colder and drier climate than today prevailed in this area at about 1500 yrs BP. As the ice sheet retreated from Marian Cove toward the northeast, the cove was inundated by a marine transgression. During this period, the waterlain tills (unit I) were exposed in the form of submarine morainal deposits on the seafloor and ice was ablated by calving actively, dumping piles of gravels and rubble onto the seafloor (Fig.6). Turbid meltwater streams might be generated during the melt season, but the stream would dissipate rapidly due to the limited input

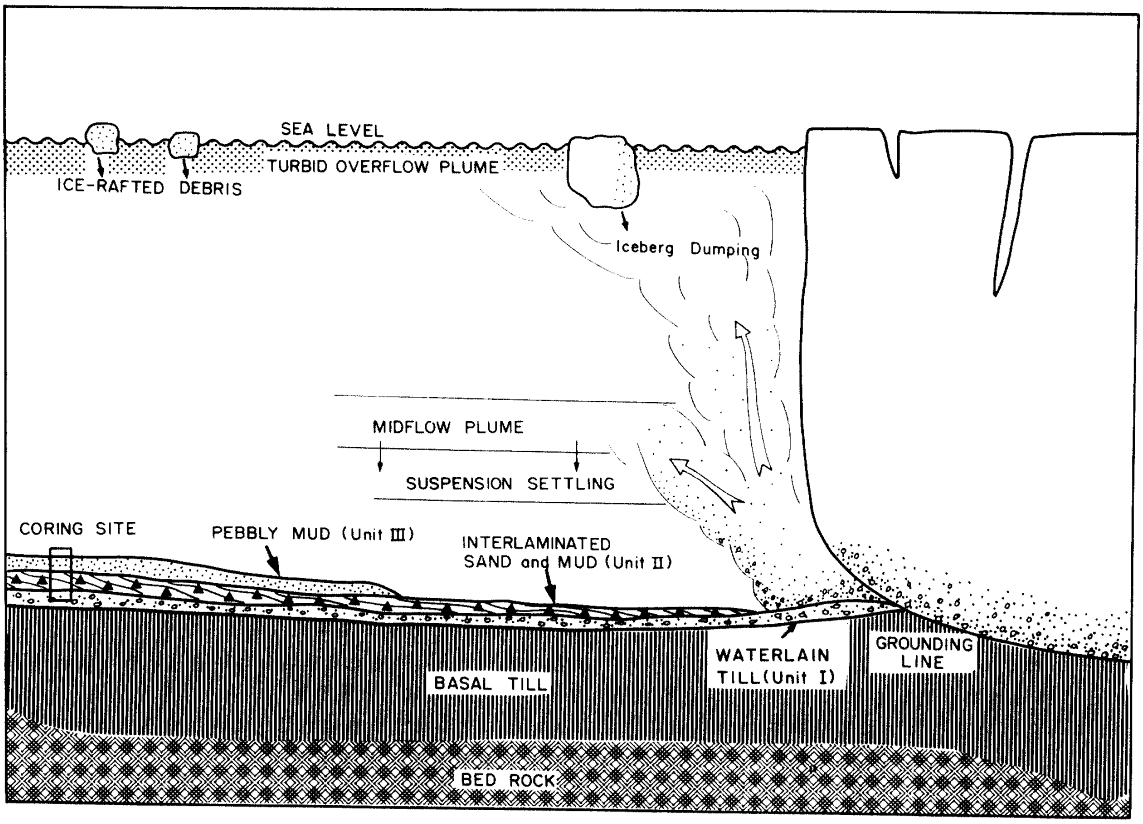

Fig. 6. Illustration of sediment types and depositional processes at retreating tidewater front of sub-polar valley glacier in Marian Cove.

of terrigenous sediment, finally rising buoyantly to become turbid midflow and/or overflow plumes (Fig. 6). Subsequently, interlaminated sand and mud (unit II) was deposited by suspension settling from these plumes, caping the underlying waterlain till (Fig. 6). With further sea lèvel rise organic-rich pebbly muds (unit III) accumulated, draping over the interlaminated sand and mud (Fig. 6).

Acknowledgments

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References

Anderson, J. B., Kurtz, D. D., Domack, E. W. and Balshaw, K. M. (1980): Glacial and glacial marine sediments of the Antarctic continental shelf. J. Geol., **88**, 399–414.

BJORCK, S., HAKANSSON, H., ZALE, R., KARLEN, W. and JONSSON, B. L. (1991): A late Holocene lake sediment sequence from Livingstone Island, South Shetland Islands, with palaeoclimatic implications. Antarct. Sci., **3**, 61–72.

DAVIS, R. E. S. (1982): The Geology of the Marian Cove area, King George Island, and a Tertiary age for its supposed Jurassic volcanic rocks. Br. Antarct. Surv. Bull., **51**, 151–165.

DOMACK, E. W. (1984): Rhythmically bedded glaciomarine environments on Whidbey Island, Washington. J. Sediment. Petrol., **54**, 589–602.

DOMACK, E. W. (1988): Depositional environments of the Antarctic continental shelf: fjord studies from the R. V. Polar Duke. Antarct. J. U. S., **23** (5), 96–102.

FOLK, R. L. and WARD, W. C. (1957): Brazos river bars. A study in the significance of grain size parameters. J. Sediment. Petrol., **27**, 3–26.

GRIFFITH, T. W. and ANDERSON, J. B., (1989): Climatic control of sedimentation in bays and fjords of the Northern Antarctic Peninsula. Mar. Geol., **85**, 181–204.

HOSKIN, C. M. and BURREL, D. C. (1972): Sediment transport and accumulation in a fjord basin, Glacier Bay, Alaska. J. Geol., **80**, 539–551.

JIN, M. S. and JWA, Ẏ.-J. (1990): Geochemistry of the volcano-plutonic rocks in the Barton and Weaver Peninsulas, King George Island, Antarctica. Korea Ocean Research & Development Institute Report, BSPG 00111-317, 101-108.

KIM, G. H. (1989): Measurements of radioactivity in sediments and estimation of sedimentation rates. Korea Ocean Research & Development Institute Report, BSPG 00081-246-7, 470–485.

KIM, W. H., KIM, M. O. and PARK, B. K. (1991): Diatoms in the Holocene sediments of the Maxwell Bay, King George Island, Antarctica. Korean J. Polar Res., **2**(1), 159–178.

LEE, B. Y. (1989): Meteorological observation from March 1988 to February 1989 at King Sejong Station. Korea Ocean Research & Development Institute Report, BSPG 00081-246-7, 174–212.

PARK, B. K., LEE, M. S., YOON, H. I and NAM, S. H. (1988): Marine geology and petrochemistry in the Maxwell Bay area, South Shetland Islands. Antarctic Science: Geology and Biology, ed by H. T. HUH *et al.* Seoul, Korea, 85–120.

POWELL, R. D. (1983): Glacial marine sedimentation processes and lithofacies of temperature tidewater glaciers, Glacier Bay, Alaska. Glacial Marine Sedimentation, ed. by B. F. MOLNIA. New York, Plenum, 185–232.

REX, D. C. (1976): Geochronology in relation to the stratigraphy of the Antarctic Peninsula. Br. Antarct. Surv. Bull., **43**, 49–58.

REYNOLDS, J. M. (1981): Distribution of mean annual air temperatures in the Antarctic Peninsula. Br. Antarct. Surv. Bull., **54**, 123–133.

SMELLIE, J. L., PANKHURST, R. J., THOMSON, M. R. A. and DAVIS, R. E. S. (1984): The geology of South Shetland Islands, VI. Stratigrphy, geochemistry and evolution. Br. Antarct. Surv. Bull., **87**, 1–85.

THOMSON, M. R. A. (1972): New discoveries of fossils in the Upper Jurassic Volcanic Group of Adelaide Island. Br. Antarct. Surv. Bull., **30**, 95–101.

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